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Patterns in the Temporal Variability of Temperate Reef Fishes and the Implications for Sampling Frequency in Citizen Science Monitoring Programs

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PATTERNS IN THE TEMPORAL VARIABILITY OF TEMPERATE REEF FISHES AND THE IMPLICATIONS FOR SAMPLING FREQUENCY IN CITIZEN SCIENCE MONITORING PROGRAMS.

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by

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ABSTRACT

Patterns in the Temporal Variability of Temperate Reef Fishes and the Implications for Sampling Frequency in Citizen Science Monitoring Programs.

by

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Masters of Science in Coastal and Watershed Science and Policy

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Ecological monitoring enables our understanding of ecosystem change and is fundamental to the process of developing sound management policies. One major gap in all current California kelp forest monitoring programs is the limited frequency at which kelp forest fishes are sampled. Citizen science has been identified as a valuable tool to help meet monitoring needs in the marine environment, most recently in the California Marine Life Protection Act (1999). Because the costs of citizen science programs are mitigated by the use of volunteers, they are more able to expand their monitoring efforts to capture seasonal variations than other professional programs. We evaluated the citizen-based Reef Check California (RCCA) for its potential to capture seasonal variations in kelp forest fishes by monitoring multiple times per year. We conducted diver surveys approximately once every four weeks from March 2009-July 2010 at MacAbee reef in Monterey, California using the RCCA fish survey protocol. We compared generalized linear models (GLM) using an Akaike's Information Criteria (AIC) approach to examine the relationship between fish abundances and time. The results of this study show that the local abundance of selected species and/or species groups were subject to substantial temporal variation both within and among oceanographic seasons. The results of this study provide information on the temporal trends of species recorded via the RCCA protocol and indicate that RCCA could expand monitoring efforts to capture continuous seasonal patterns, change between oceanographic seasons, and within season variability. This information, combined with information from other professional organizations can ultimately better inform marine management decisions.

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Introduction

Ecological monitoring enables our understanding of ecosystem change and the natural and anthropogenic factors that drive change. Such knowledge is fundamental to the process of developing sound management policies (Underwood 1994; Dayton et al. 1998). Any ecological monitoring program must contend with two primary issues: ensuring that the data are as accurate as possible, and that the amount of information that is produced per unit effort is maximized relative to the costs incurred. A successful monitoring program will balance these potentially competing issues to produce robust, accurate information in a cost effective manner.

Effects of Temporal Variability on Accuracy of Monitoring

Fish communities fluctuate naturally as a function of a variety of environmental factors. In California marine fishes respond to many natural drivers, including storms, algal assemblage shifts, upwelling, or recruitment events (Miller & Geibel 1973; Terry & Stephens 1976; Stephens et al. 1984; Dayton 1985; Ebling & Laur 1986; Holbrook et al. 1990; Anderson 1994; Carr 1994; Levin & Hay 1996; Magill & Sayer 2002, 2002). Temporal variation in the abundance of kelp forest fishes takes place on scales ranging from days (Bray 1981), to months (Thresher et al. 1989), seasons (Terry & Stephens 1976; Carr 1991), and years (Schmitt & Holbrook 1990; Holbrook et al. 1990).

Characterizing these natural variations is necessary to first understand, and then subsequently to, monitor the ecological processes that drive ecosystem change.

Knowledge about trends and patterns of species being measured should be incorporated into any monitoring plan so that monitoring is sufficient to identify patterns of change at a scale equivalent to the natural variation in the population (Underwood 1994). If these patterns are not characterized temporal variability can complicate the interpretation of results and ultimately delay or misinform management actions (Dayton et al. 1992; Costanza et al. 1999; MLPA Central Coast Monitoring Plan 2006).

Data collected from monitoring programs are used to track the ecological changes in the marine environment and help guide management and regulatory decisions (National Research Council 1990a; Dawson & Shuman 2009). Most recently, such monitoring data were used in the implementation of the California Marine Life Protection Act (MLPA), which required the state to designate a state-wide network of marine protected areas (MPAs). As of January 1, 2012, eighty-six MPAs will have been implemented from the Mexican boarder to Pt. Arena (north of San Francisco), with the rest of the state to be completed by the end of 2012. One of the requirements of the MLPA is that monitoring be conducted "to ensure the MPA network meets its stated goals, to provide information on the effects of management actions, and to improve understanding of marine systems" (CDFG 2005). The monitoring design of the MLPA is structured around monitoring the inside and outside of reserves annually to track the effects of the closed areas over time (MLPA Central Coast Monitoring Plan 2006). Currently efforts are not made to continually monitor seasonal variations in fish populations in the MLPA monitoring plan, even though these patterns are integral to understanding marine systems, specifically those within MPAs. Additionally, if not characterized, natural temporal variability could jeopardize the accuracy of the data being collected (Stevens et al. 1984; Maxwell &Jennings 2005).

Citizen Scientists as a Means to Enhance Monitoring

Traditionally environmental monitoring in general, and off the coast of California specifically, has been the purview of government agencies and/or academic institutions. These agencies/institutions have ben the gold standard in monitoring because they use

highly trained research divers and the resulting data are very reliable (Milligan et al. 2006). However, increasingly citizen-based groups are contributing to ecosystem monitoring (Foster-Smith & Evans 2003; Pattengill- Semmens & Semmens 2003; Delaney et al. 2008; Schmeller et al. 2008). By incorporating volunteers in monitoring studies, citizen-based monitoring programs can augment professional monitoring programs by increasing the spatial or temporal scope or intensity of monitoring with little increased costs (Pattengill-Semmens & Semmens 1998, 2003). Because of this, citizen-based data collection has become an alternative for scientists and resource agencies who need information but lack sufficient resources to gather it (Cuthill 2000; Foster-Smith & Evans 2003; Pattengill-Semmens & Semmens 2003).

In the United States, the earliest example of engaging citizen scientists in environmental monitoring was the use of volunteer observers by the National Weather Service to record rainfall and air temperature in the late 19th century (Firehock & West 1995). Since the early 1900s volunteers have also played a central role in several bird observation programs through the National Audubon Society's Christmas Bird Count (started in 1900) and the U.S. Fish and Wildlife Service's Bird Banding Program (started in 1920) (Lee 1994). In the marine environment, the National Marine Fisheries Service has used volunteers since 1954 to track fish populations through tag and release methods (Lee 1994).

Worldwide, citizen science has been identified as a valuable tool to help meet monitoring needs in the marine environment (Pattengill-Semmens & Semmens 1998). One of the first citizen SCUBA-based monitoring organizations was the Reef Environmental Education Foundation (REEF) fish-monitoring project, which started in Florida in 1993 and has since expanded to coasts all over the world (Pattengill-Semens & Semens 2003). The Reef Check Foundation started in 1996 uses scientifically trained volunteers to monitor tropical marine systems in over 90 countries. Unlike REEF, Reef Check utilizes sampling methods modified from scientific monitoring programs to facilitate their inclusion into professionally obtained datasets (Hodgson et al. 2004). Reef Check also provides volunteers with extensive training, more than most citizen science

programs. They do this in an attempt to minimize the difference between their results and results obtained by professional programs and ultimately provide data at the level of quality required to meet the needs of managers and decision makers (Hodgson et al. 2004; Gillett et al 2011).

Several kelp forest and rocky reef monitoring organizations are currently operating in California, led by academic, government, private, and non-profit institutions, some of which involve volunteers (Dawson & Shuman 2009). The oldest kelp forest and rocky reef monitoring organization in California is the professional Kelp Forest Monitoring Program (KFMP) started by the Channel Islands National Park, which has used trained research divers to conduct community monitoring in the Channel Islands since 1982 (Davis et al. 1997). The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO, started in 1999) is an academic organization, which uses trained research divers to monitor over 60 sites along the California and Oregon coast, and has become the most prominent underwater monitoring organization in California (Milligan et al. 2006). Although PISCO monitors a large geographic area, the spatial and temporal resolution of their effort is constrained in its extent by the fiscal and personnel limitations involved in using scientific divers. In 2006 Reef Check started its California program (RCCA) with the primary objectives to create a statewide, standardized citizen-based monitoring program designed to monitor the ecological communities on rocky reefs, and provide marine managers with robust scientific data needed to make sustainable management decisions (Dawson & Shuman 2009).

Citizen science-based monitoring has been identified as a valuable tool to help meet the monitoring needs of the MLPA (CDFG 2005). Citizen science-based kelp forest community monitoring data, including RCCA, were integral in implementing and conducting baseline monitoring for the north-central and south coast sections of the MLPA; and will continue to be used to designate further MPAs and for adaptive management of existing MPAs (CDFG 2006).

One of the major gaps in all current California kelp forest monitoring programs is the limited frequency at which kelp forest fishes are sampled. RCCA has the potential to

expand its monitoring effort temporally, due to its efficient survey protocol and its use of trained volunteers, thus filling this monitoring gap in California. By doing this it may be able to provide more complete information and complement other organizations such as PISCO to better inform marine management decisions. To this end, we evaluated the citizen-based monitoring protocol of the Reef Check California (RCCA) program for its potential to characterize seasonal variations in kelp forest fishes by increasing its sampling frequency. The objectives of this study were: 1) to quantify any seasonal variation in the abundance and species richness of kelp forest fishes at a single location over an 18-month period, 2) to evaluate the implications of seasonal variation in fish communities for monitoring data collected less frequently by sub-sampling the 18 months of data at multiple frequencies, and 3) to evaluate data collected using the RCCA protocol in relation to longer-term (but lower frequency) data collected using the PISCO protocol.

Research Design and Methods

Study Site

We conducted diver surveys at the southern end of MacAbee reef off Monterey, California (36.62°N, 121.89°W; Fig1). MacAbee Reef is a *Macrocystis pyrifera* (Giant Kelp)-dominated kelp forest with a seasonal understory of *Laminaria spp*. Depth ranges from 5 m - 20 m and the seafloor is of medium rugosity (0 m - 2.0 m), primarily composed of bedrock and boulder (Shuman 2007). MacAbee reef is located within the Edward F. Rickets State Marine Conservation Area, which prohibits the take of all living marine resources except the recreational take of finfish by hook-and-line and the commercial take of *Macrocystis pyrifera* (Fish and Game Code Section 2852). This location is accessible year round and has multiple years of data collection from both PISCO and RCCA.

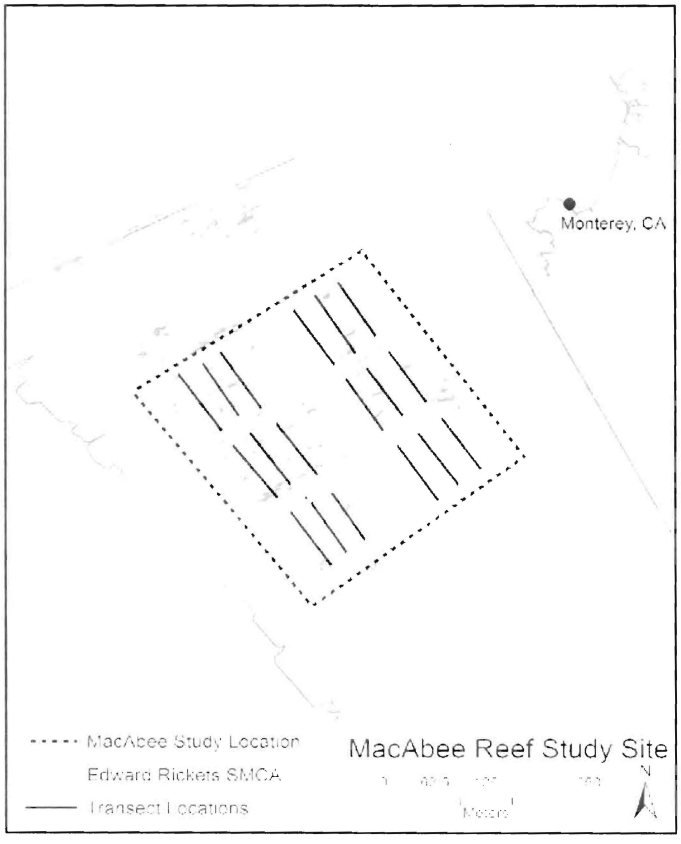

Figure 1. Study location with relative transect locations at MacAbee Reef in Monterey, California.

Sampling Procedure

We conducted diver surveys approximately once every four weeks from March 2009-July 2010 at MacAbee reef using the RCCA fish survey protocol (Dawson & Shuman 2009,Appendix B). We established target survey dates at four-week intervals with a one-week buffer on either side to create two-week sampling windows. Individual surveys were separated from each other by 3-5 weeks depending on diving conditions. Surveys consisted of 18 band transects: nine inshore and nine offshore. Inshore transects were done along 7.5 m, 9.0 m, and 10.5 m isobaths and offshore transects were done at 13.5 m, 15.0 m, and 16.5 m isobaths (Appendix A). We conducted three transects along each isobath. There were always at least 5 m between each transect in a line and at least 5 m between lines. A minimum of 5 m visibility was required to complete any transect based on RCCA protocol. In a preliminary survey we evaluated the effect of visibility from 5 m - 10 m and found it to have no effect on fish observations for any of the species observed during this study (Appendix E).

Fish in a given three-dimensional volume (30 m long x 2 m wide x 2 m tall) were recorded in transects along the bottom of the seafloor (Appendix A). All 33 fish species on the RCCA species list were identified and where possible fish size and sex were also recorded (Table 1; Appendix B). Divers swam at a constant speed of 3 - 5 m/minute and recorded fish that entered an invisible 2 m x 2 m x 2 m box ahead of them. Divers used a sectioning technique where they recorded fish in sequential windows of 2m using habitat markers to define their sections. First they counted large mobile fishes immediately in front of them. They then searched for and counted unexposed fishes until they reach the end of that section. Flashlights were used to aid in the identification of fish species as well as to see fish in crevices.

Table 1- Species from RCCA species list that were encountered on transects over the study period. * Indicates a species was observed in over 50% of the surveys.

Family	Species name	Common name
Scorpaenidae		
	*Sebastes atrovirens**	kelp rockfish
	Sebastes auriculatus	brown rockfish
	*Sebastes carnatus**	gopher rockfish
	*Sebastes caurinus**	copper rockfish
	*Sebastes chrysomelas**	black and yellow rockfish
	*Sebastes flavidus/ Sebastes serranoides**	olive/yellowtail rockfish
	*Sebastes melanops**	black rockfish
	Sebastes miniatus/ Sebastes pinniger	vermillion/ canary rockfish
	*Sebastes mystinus**	blue rockfish
	Sebastes rastrelliger	grass rockfish
	Sebastes serriceps	treefish
Embiotocidae		
	*Damalichthys vacca**	pile perch
	*Embiotica lateralis**	striped perch
	*Embiotica jacksoni**	black perch
	Hypsurus caryi	rainbow perch
	*Rhachochillus toxotes**	rubberlip perch
Hexagrammidae		
	*Hexagrammos decagrammus**	kelp greenling
	Ophiodon elongatus	lingcod
Cottidae		
	Scorpaenichthys marmoratus	cabezon
Serranidae		
	Paralabrax clathratus	kelp bass
Labridae		
	Oxyjulis californica	senorita
Pomacentridae		
	Chromis punctipinnis	blacksmith
Kyphosidae		
	Girella nigricans	opaleye

Statistical Methods

Temporal variation in measured parameters

By sampling MacAbee reef approximately every four weeks for 18 months, we were able to characterize the any seasonal variation in the response variables with time. We considered four types of response variables: total abundance, species richness, family groups abundance, and individual species abundance because they have consistently been shown to be important indicators of population change (Stephens et al. 1984; Ebling & Laur 1986; Anderson 1994; Levin &Hay 1996; Jackson &Jones 1999; Magill & Sayer 2002). Total abundance was the total number of fish observed in one survey. Species richness was the total number of species observed in one survey. Family group abundance was number of fish observed in one survey within a phylogenetic family group. Individual species abundance was number of fish observed in one survey within an individual species. For all response variables an entire monthly survey was used as an individual sampling unit because although multiple transects are used in one survey, surveys were designed to include all transects as one sample, not as replicates.

For each of the four response variables, the overarching postulate examined in this study is: There is a non-zero relationship between the response variable and time (Appendix D). Based on this postulate, we made the following hypotheses:

$\boldsymbol{H_1}$ – There is no relationship between the response variable and time.
$\boldsymbol{H_2}$– There is a non-zero linear relationship between the response variable and time.
$\boldsymbol{H_3}$– There is a periodic relationship between the response variable and time.

We examined the relationship between each response variable and time using a generalized linear model (GLM) comparison with a negative binomial error distribution in the MASS package in the R statistical program (R Developmental Core Team 2008). The Negative Binomial error distribution was decided upon by assessing the standardized residuals, leverage, and normal QQplots (Neter et al 1985). In addition, our count data

showed considerable over-dispersion (variance is larger than the mean) indicating the Negative Binomial error distribution was most appropriate (Ismail & Jemain 2007).

The model comparison for each response variable was comprised of the following components:

$$H_0 : Y = \beta_0 \cdot tac + \varepsilon_i = 0$$

$$H_1 : Y = \beta_0 + \beta_1 t \cdot tac + \varepsilon_i$$

$$H_2 : Y = \beta_0 + \beta_1 \cos\left(\frac{2\pi}{P} t\right) + \beta_2 \sin\left(\frac{2\pi}{P} t\right) tac + \varepsilon_i$$

where:

Y was the response variable, β_0, β_1, and β_2 were coefficients, t was time in days, P was the known period, *tac* was the temporal autocovariance variable, and ε_i was the error term (Negative Binomial)

For each response variable we compared the models using the Akaike's Information Criteria (AIC) approach to examine the influence of the predictor on the response variable (Burnham and Anderson 1998, 2002, 2004). We calculated the AIC_C, which should be used whenever the sample size is 30% or more of the degrees freedom and AIC weight (AIC_w), which represents the probability that each model was the best-fit model and presented these results in an AIC comparison table. For each comparison, we inferred which model was best able to predict the response variable (Y) from the model with the lowest AIC_C values (Burnhan & Anderson 2004). In addition, an evidence ratio (ER) was calculated to quantify the strength of the evidence supporting the best-fit model (Burnham and Anderson 2002, 2004).

For species abundance and family group abundance the AIC was run separately for each species or group of species and only species or groups that were present in 50% of the surveys were used (Micheli & Halpern 2005). Temporal autocorrelation was investigated using the autocorrelation function (ACF) in R, which gives the order of the best-fit autoregressive model (AR) (Appendix D). Those response variables that had an AR>0, were run using a Generalized Least Squared model (GLS) in the *nlme* package in R, which allows for an autocorrelation term in the model (Bolker

2008). For each of the response variables, if the H_2 hypothesis was supported, we subsampled at 6 sample per year intervals and re-ran the model comparison. By doing this analysis we were able to determine if it was possible to detect seasonal variations by sampling at less frequent intervals.

Oceanographic Season Analysis

As the frequency required to capture seasonal fish variations increases, inherently the feasibility of being able to sample at that frequency decreases (Schiell 2001). An alternative to sampling at a rate that fully captures seasonal changes is to sample once during each oceanographic season. In Monterey, California there are two generally accepted separate oceanographic seasons: upwelling (April-Sept) and non-upwelling (Oct-March) (Hallacher & Roberts 1985; Graham 1993). We investigated if there was a statistical difference between the populations recorded by the RCCA protocol during the two oceanographic seasons. To do this analysis we grouped monthly surveys into these upwelling and non-upwelling months and conducted Students t-tests. To assess whether the assumption of normality was met we used the Shapiro-Wilks test (Shapiro & Wilks 1965) and examined normal QQplots (Neter et al 1985). All response variables had normal distributions except for *S. carnatus, S. caurinus, S. chrysomelas, S. mystinus, S. melanops, D. vacca, R toxotes*, and Scorpaenidae group, which were square-root transformed to satisfy normality requirements.

Young of the Year Sebastes mystinus Analysis

As per the RCCA protocol a "small" fish is anything that can be identified as its adult form and under 15cm total length (Dawson & Shuman 2009). Young of the year (YOY) *S. mystinus*, 16-80mm total length (Miller & Geibel 1973; Anderson 1983) are identifiable to species as at a much smaller size than most other rockfish species, and therefore are recorded as small *S. mystinus* during RCCA surveys when other species of YOY are not. This can create large variation in the abundance of *S. mystinus* due to seasonal recruitment pulses of YOY *S. mystinus* (Stevens 1981; Carr 1991). We re-ran all analyses after excluding small *S. mystinus* observations from the dataset and qualitatively compared the results.

Results

Temporal variation in measured parameters

In total 1319 fish were observed at MacAbee reef between March 2009 and July 2010. A total of 23 species from eight families were recorded across 15 surveys. Three surveys were not completed (Oct '09, Jan '10, and May '10) due to either strong storms or poor visibility from algae blooms (Appendix B). Fish abundance fluctuated markedly during the 17 months of sampling. A general trend of low counts per survey were observed during the early months of the year (February-April) with a gradual increase in the number of individuals over the summer months, culminating in peak abundance recorded in August-September (Fig 2). Twelve species were seen in at least 50% of the transects and three families: Scorpaenidae, Hexagrammidae, and Embiotocidae (Table 1). *H. decagrammus* was the only species recorded in the Hexagrammidae family and therefore Hexagrammidae was excluded from the family group analysis. Embiotocidae group was the only response variable to test positive for temporal autocorrelation with an AR (1), and therefore the AIC analysis was run using the GLS method.

The periodic model was the best-fit model in the AIC analysis for several species and groups (Fig 2, Table 2, Appendix F). All of the species or groups for which the periodic model best described the monthly variability in abundance exhibited similar trends (Fig 2). Although their wave amplitude and median varied markedly, the maximum count for all species or group was in August or September, and the minimum was always in March. When surveys were subsampled at an interval of six samples pear year, the null model (i.e. no pattern of seasonal variation) was the best for all of the response variables.

Species of surfperches (family Embiotocidae) showed periodic patterns more than other families. The periodic model was the best fit for the Embiotocidae family as well as *E. lateralis*. Additionally, three of the four observed species showed an increased abundance during August and September. Although *E. lateralis* was the most common species within the Embioticadae, comprising 45% of the total family abundance it is

possible that the other species, although they did not accept the periodic model, also contributed to both the periodicity of Embiotocidae and Total Abundance periodic patterns.

Oceanographic Season Analysis

T-tests revealed that there was a significant difference ($p<0.05$) between upwelling and non-upwelling seasons for the several species and groups (Table 3, Appendix F). For all of these differences, counts were always higher in the upwelling season. All of the response variables for which the periodic model was the best fit in the AIC analysis also showed a difference between the two oceanographic seasons with the exception of the Embiotocidae group. In addition, *S. chrysomellas* which had not shown a periodic pattern in the AIC analysis, did show a difference between the two oceanographic seasons.

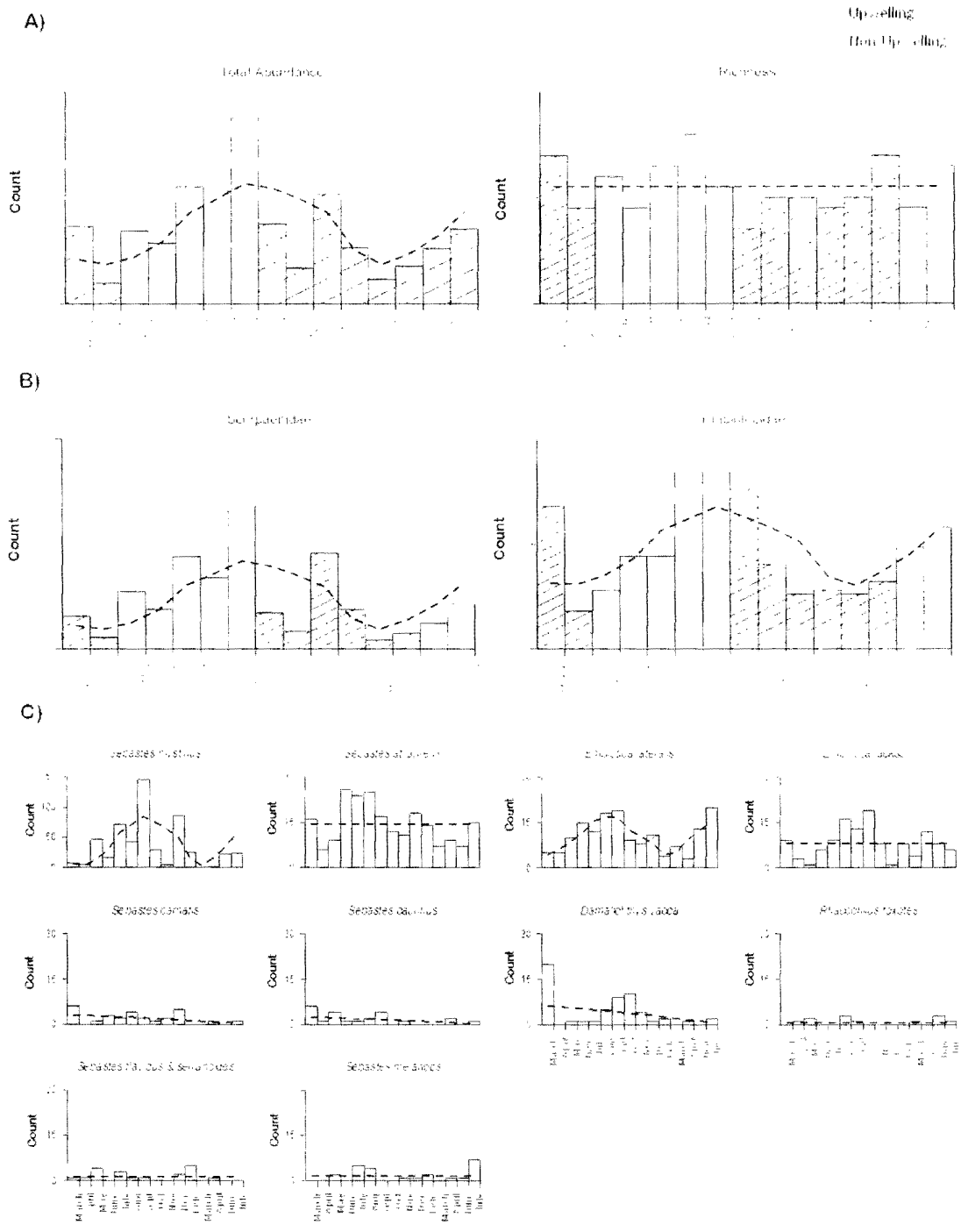

Figure 2. Total counts observed for all response variables per survey (bar plot) with predicted best fit model from AIC analysis (line plot). Slope of the line indicates which model was the best fit, and shows the actual predicted trend for the model. A) Plots for total abundance and species richness, B) Plots for family group abundance, B) Plots for individual species abundance.

Table 2- Comparison of three hypotheses about temporal variation in response variables. AIC table is comparing the three hypotheses for each species and group using monthly sampling interval. Bold indicates the best-fit model.

	df	*AICc*	*AICw*
Total Abundance			
Null (H_0)	2	160.81	0.2
Linear (H_1)	3	162.97	0.06
Periodic (H_2)	4	**158.23**	**0.73**
Scorpaenidae			
Null (H_0)	2	153.73	0.28
Linear (H_1)	3	155.55	0.11
Periodic (H_2)	4	**152.15**	**0.61**
Embiotocidae			
Null (H_0)	2	116.59	0.33
Linear (H_1)	3	119.54	0.07
Periodic (H_2)	4	**115.41**	**0.59**
Sebastes mystinus			
Null (H_0)	2	142.42	0.26
Linear (H_1)	3	144.65	0.08
Periodic (H_2)	4	**140.61**	**0.65**
Embiotica lateralis			
Null (H_0)	2	96.52	0.01
Linear (H_1)	3	99.62	0
Periodic (H_2)	4	**86.13**	**0.99**

Table 3- A test for seasonal variation in response variables. t-tests show significance of the differences in abundance between the oceanographic seasons for each species and group.

	t	*df*	*Probability*
Total Abundance			
	-2.03	10.39	0.07
Scorpaenidae			
	-2.27	12.51	0.04
Embiotocidae			
	-1.49	12.74	0.16
Sebastes chrysomelas			
	-2.35	12.96	0.04
Sebastes mystinus			
	-2.14	12.73	0.05
Embiotica lateralis			
	-5.06	10.72	0.0004
Rhachochillus toxotes			
	-2.27	9.87	0.05

Young of the Year *Sebastes mystinus* Analysis

When small *S. mystinus* were removed from all response variables that included *S. mystinus* counts, the null model (i.e. no pattern of seasonal variation) was the best for all response variables (Table 4, Appendix F). However, when small S. mystinus counts were considered independently, the periodic model was the best fit (Table 4). These results are different from the analysis including small blue rockfish and indicate that small *S. mystinus* were responsible for the periodic trends seen in the AIC analysis on the complete dataset. Because the periodic pattern was not seen in adult S. mystinus, Scorpaenidae group, or Total Abundance when small S. mystinus were removed, and small S. mystinus by themselves showed highly periodic patterns, it indicates that the only periodic pattern in all Scorpaenidae species is only due to the seasonal pattern of small S. mystinus.

Results of t-tests between upwelling and non-upwelling seasons when small *S. mystinus* counts were removed showed that there was a significant difference for most of the response variables including when small *S. mystinus* were considered as an independent group. The results of these analyses indicate that unlike in the AIC analysis, small *S. mystinus* may contribute to, but were not solely responsible for the seasonal differences seen in these groups.

Table 4 - Comparison of three hypotheses about temporal variation in response variables excluding small S. mystinus. AIC table is comparing the three hypotheses for each species and group using monthly sampling interval. Bold indicates the best-fit model.

	df	*AICc*	*AICw*
Total Abundance			
Null (H_0)	2	147.23	0.59
Linear (H_1)	3	149.17	0.22
Periodic (H_2)	4	149.48	0.19
Sebastes mystinus			
Null (H_0)	2	112.1	0.63
Linear (H_1)	3	113.43	0.33
Periodic (H_2)	4	117.66	0.04
Scorpaenidae			
Null (H_0)	2	134.3	0.54
Linear (H_1)	3	134.97	0.39
Periodic (H_2)	4	138.45	0.07
Small Sebastes mystinus			
Null (H_0)	2	127.46	0.08
Linear (H_1)	3	130.3	0.02
Periodic (H_2)	4	**122.73**	**0.89**

Table 5 - A test for seasonal variation in response variables excluding small *S. mystinus*. t-tests show significance of the differences in abundance between the oceanographic seasons for each species and group.

	t	*df*	*Probability*
Total Abundance			
	-2.15	12.70	0.05
Sebastes mystinus			
	-2.30	10.37	0.04
Scorpaenidae			
	-2.14	12.73	0.08
Small Sebastes mystinus			
	-3.01	11.25	0.01

Discussion

In this study we characterized patterns in the seasonal occurance of selected temperate reef fishes sampled via the RCCA protocol at MacAbee Reef in Monterey California. The results clearly show that the local abundance of selected species and/or species groups were subject to substantial temporal variation both within and among oceanographic seasons. It is important to characterize the seasonal variations within populations so that monitoring programs can not only monitor the demographic processes that drive the variations themselves, but also incorporate this information into their design so that their results are not influenced by natural stochastic variations. Therefore, the utility of the data produced by any monitoring program will be dependent on the demographic processes that drive the populations, which will in turn influence the management objectives that the data will ultimately inform.

Ecological Implications

Many of the patterns we observed were consistent with previous research related to the demographic processes underlying seasonal changes in fish populations. Kelp density and storms have been cited as environmental factors that can have a major influence on temperate shallow water reef fish populations (Stevens 1984, Holbrook et al 1990, Carr 1994). Along the California coast, the density of the brown alga *Macrocystis pyrifera* can positively influence the size and structure of fish populations associated with it and can exhibit extreme temporal variability, thus creating seasonal variations in the occurrence of the associated fishes (Dayton 1985; Ebeling et al. 1985; Schiel & Foster 1986; DeMartini & Roberts 1990; Holbrook et al 1990; Holbrook et al. 1994). In this study the maximum fish abundances were recorded in the summer months when kelp canopies were densest in Monterey, which may have positively influenced the fish populations.

Storms also directly influence kelp forest fish populations on a seasonal scale. Unfavorable storm conditions can cause fish to use refuges by hiding in crevices in the seafloor and/or move offshore during winter months (Miller & Geibel 1973; Sayer et al.

1994; Nickell & Sayer 1998). Additionally, storms can rip out kelp canopies, which can negatively impact fish populations especially for those species that associate with the kelp canopies (Miller & Geibel 1973). During this study period the most severe storms in the Monterey Bay occurred in January and February, which resulted in our not being able to perform the January 2009 survey, and in two of the lowest counts of fish in February 2009 and 2010.

Literature suggests that the Embiotocidae group responds to seasonal changes in the marine environment more than other families. For example, the density of Embiotocidae is closely correlated to the density of giant kelp, both of which vary on a seasonal basis (Ebeling et al. 1985; Holbrook et al 1990; Anderson 1994). Embiotocids also respond heavily to storms. For instance, Bodkin (1987) reported incidents of mortality of adult Embiotocid species after severe storms off the California coast. In this study species of surfperches (family Embiotocidae) overall showed periodic patterns more than other families, which was likely due to these demonstrated patterns.

In this study we saw a pulse of small *S. mystinus* in the upwelling months, which created a significant periodic pattern in this population. This was essentially the only periodic pattern observed in the entire Scorpaenidae group. This was likely due to young of the year recruitment pulses. Recruitment of young of the year fish has a large seasonal component and usually coincides with large upwelling events in the spring (Carr 1989; Fowler 1990; Carr 1991; Doherty 1991; Cowen & Bodkin 1993; Holbrook 1994). However, significant difference in multiple species when oceanographic seasons were compared held up even when small *S. mystinus* were removed meaning that even though small *S. mystinus* were the driving factor for the periodic trend, adults of Scorpaenid species do show a difference in abundance between oceanographic seasons.

Implications for Monitoring Programs

Ecological monitoring is conducted for various purposes; it is generally intended to document ecological patterns and processes, which later serve as the basis for sampling designs, trend monitoring, and to identify and quantify longer-term environmental

changes anticipated as a possible consequence of human activities (NRC 1990; Baird 2000). The MLPA's Monitoring program is structured around monitoring any differences inside and outside of reserves annually in order to inform adaptive management of the MPAs (MLPA Central Coast Monitoring Plan 2006). However, the goals of the MLPA are vast and require the biological monitoring of systems that exist on various temporal scales (MLPA Central Coast Monitoring Plan 2006). It is important for the sampling effort to be sufficient so that the goals of the monitoring plan can be met and ultimately management can best be informed. Understanding or creating a conceptual model of relevant temporal trends and patterns can aid in ensuring effective monitoring design (MLPA Central Coast Monitoring Plan 2006). The results of this study provide information on the temporal trends of species recorded via the RCCA protocol and indicate that RCCA could expand monitoring efforts to capture continuous seasonal patterns by sampling monthly, monitor seasonal change by sampling at both oceanographic seasons, as well as increase the reliability of annual data by monitoring the within season variability.

This study showed that by monitoring monthly RCCA can monitor recruitment pulses of *S. mystinus* as well as post-recruitment processes, which can have implications for MPA evaluation (Sale et al 1985; Syms and Carr 2001; Johnson 2006a,b 2007). Larval production is an important indicator for evaluation of individual MPAs as well as the MPA network as a whole. Reserves can cause increased larval production within MPA boundaries and larval dispersion can replenish fish populations outside MPAs (Syms and Carr 2001).

This study also indicated that RCCA could provide information on the seasonal differences in populations of both Scorpaenidae and Embiotocidae families by sampling in each oceanographic season. RCCA would then be able to treat seasonal variation as a process with structure in order to identify patterns of change at a scale equivalent to the natural variation in the population. This is particularly important when the comparison of sites are used to make inferences on the effectiveness of reserves, and not considering seasonal patterns could jeopardize the accuracy of results. RCCA already conducts two

surveys in Monterey, once during late summer in the upwelling season, and one during spring which usually falls in the non-upwelling season. These results stress to RCCA the importance of establishing target survey dates within both the upwelling and non-upwelling seasons, so that these patterns can most accurately be identified.

This study illustrated that the reef fish populations in Monterey, California are subject to substantial temporal variation within oceanographic seasons as well. Our results showed that the total abundance and family abundance counts during the upwelling season all fall within the range of abundances observed over the past ten annual surveys conducted by PISCO, suggesting that stochastic intra-seasonal variations can significantly influence estimates of species abundances (Appendix G). If PISCO or RCCA did not pay close attention to sampling at the same time annually, changes to the populations would have to exist on a scale greater than the within season variation in order to be detected. PISCO and RCCA may be detecting true changes in the fish populations on an annual basis; however, they are unable to reject the possibility that their data are influenced by natural stochastic variation. PISCO attempts to ameliorate the issue of seasonal variation by sampling at the same time each year, in late summer when species counts are highest, and by conducting two replicate surveys per site or four replicate surveys per MPA. However, the opportunity to increase sampling effort within the upwelling season would reduce error around the annual estimates and increase power to detect inter-annual trends. With the use of volunteers RCCA has the ability to increase sampling effort to monitor multiple times during the upwelling season. They can use this information not only to make inferences about their own data, but also to inform other monitoring organizations such as PISCO of the within season variation that is occurring around their sampling dates.

Utility of Citizen Science Programs

Accurate, consistent, and complete data describing California's near shore marine ecosystems are critical to the successful management of these systems. As long as the infrastructure of citizen science programs is put in place (training guidelines, volunteer

coordination, data management), streamlined efficient training programs enable large numbers of volunteers to collect data, faster than any professional program (Cooper 2007). This additional information can be used to characterize the relevant temporal patters of indicator species to aid effective monitoring. The information we provided here can be used to make decisions on how to expand monitoring efforts and ultimately better inform management. The benefits RCCA gains by utilizing an efficient survey protocol coupled with cost effective volunteers, enables them to expand their monitoring efforts and provide information on natural seasonal fish variations. This information, combined with information from other professional organizations can ultimately better inform marine management decisions.

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APPENDIX A- ADDITIONAL INFORMATION ABOUT FIELD SAMPLING

Sampling Procedure

Diver surveys were conducted approximately once every four weeks from March 2009-July 2010 at MacAbee reef using the RCCA fish survey protocol (Dawson &Shuman 2009). Surveys were conducted at approximately the same phase of the lunar cycle to prevent possible influences from moon phase affects (Foster 1987; Rooker & Dennis 1981). Target dates were set every four weeks with a one-week buffer on either side to create two-week sampling windows. Therefore, samples were separated 3-5 weeks from each other based on diving conditions. Surveys consisted of 18 band transects: nine inshore habitats and nine offshore habitats (Fig A1). Inshore habitat transects were done along 7.5 m, 9.0 m, and 10.5 m isobaths and offshore transects were done at 13.5 m, 15.0 m, and 16.5 m isobaths. Three transects were conducted along each isobath. There were always at least 5 m between each transect in a line and at least 5 m between lines (Fig A1).

Buddy pairs were assigned a transect depth and compass heading in advance of a dive. Specific transect location within the depth range were determined opportunistically based on the presence of rocky substrate. Transects were not placed in areas where there was is at least 10 m of continuous sand or where the depth varied by 3 m above or below the starting depth. A minimum of 5 m visibility was required to complete any transect. The effect of visibility from 5 m - 10 m was tested post hoc and found to have no effect on fish observations.

Surveys were conducted using strip transects where all specified fish in a given three-dimensional area (30 m x 2 m x 2 m) of the bottom were recorded. All specified fish on the RCCA species list as well as size and sex (when appropriate) were recorded (Fig A2). Divers swam at a constant speed of 3 - 5 m/minute at a height of 0.5 m off the bottom and recorded fish that entered an invisible box 2 m x 2 m x 2 m ahead of them (Fig A2). Divers used a sectioning technique where they recorded fish in sequential windows of 2 m using habitat markers to define their sections. First they counted large

mobile exposed fishes immediately in front of them, then they searched for and counted unexposed fishes until they reach the end of that section. Flashlights were used to aid in the identification of fish species as well as to see fish in crevices. Once a diver buddy pair reached the end of the 30 m transect, they un-attached and reeled up the meter tape, swam at least 5 m along the same compass heading, and started again

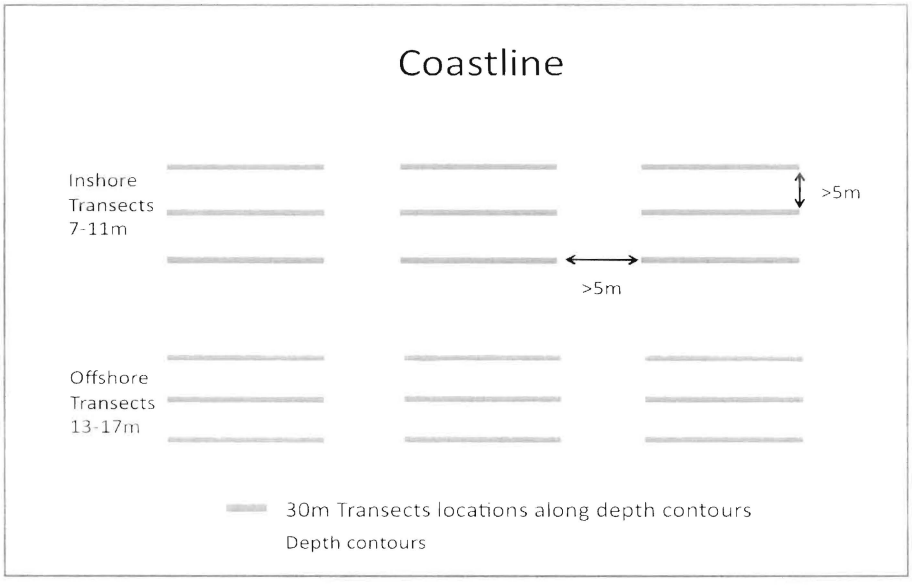


Figure A.1. Diagram of transects positions that compose an entire survey.

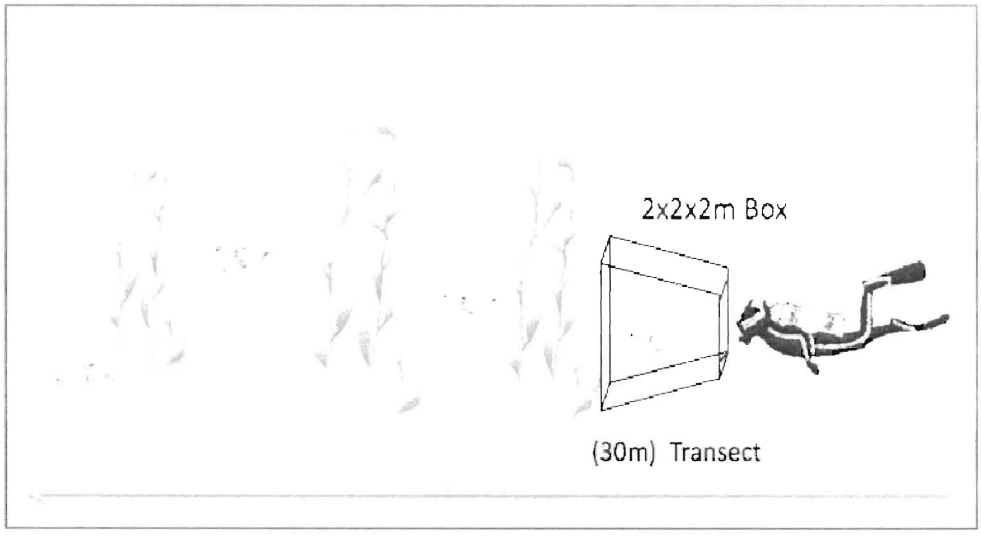


Figure A.2. Position of diver and survey area in the water column.

Volunteers

In order to conduct surveys and record data, volunteers must have successfully completed the RCCA training course and be an active California State University Monterey Bay (CSUMB) scientific diver. A skills test was performed which consisted of co-conducting a transect with the project leader and comparing the data collected. The skills test helped control for diver error between transects. Immediately following every dive, each data collector reviewed his or her data sheet for completeness and legibility. The project leader verified this prior to collection of each sheet and discussed any potential outliers with the data collector. This debriefing helped enhance precision and accuracy of fish counts as much as possible.

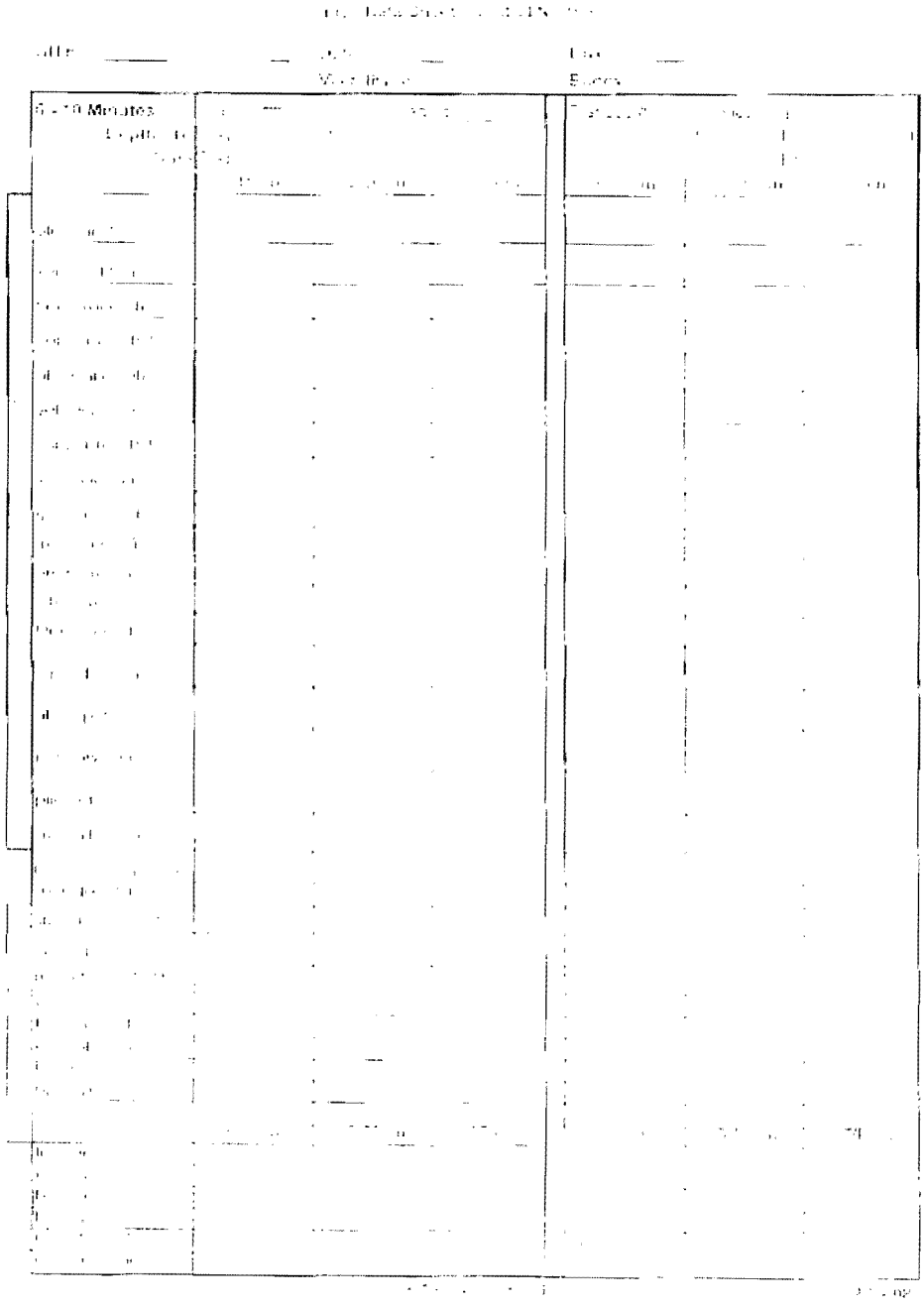
Dive Plan

Dive profiles were approved by the CSUMB diving safety officer before diving operations began. Dives were conducted well within no-decompression limits with a maximum dive depth of 18 m and mandatory three to five minute safety stops on all dives below 9 m. Inshore transects were done at a depth of 7.5m to 10.5m and offshore transects were done at a depth of 13.5m to 16.5m. Dive time was approximately 45 minutes per dive with at least a one-hour surface interval. In a given day, deep dives always preceded shallow dives. Two dives were conducted per day and pending visibility and ocean conditions, a maximum of three days was needed to complete the entire survey.

Data Storage and Analysis

Data was recorded in the field on data sheets printed on underwater paper. All data sheets were collected, photo-copied, and entered into an excel database immediately following each survey. In addition to fish data, all information recorded on the dive day including data collector, transect number, start and end depth, and compass heading will be entered in the database for that survey. All data was backed up on an external hard drive and photocopies of data sheets were archived for reference

APPENDIX B- SAMPLE RCCA FISH DATA SHEET



APPENDIX C- SAMPLING DAYS AND OBSERVERS

Table C.1 Sampling dates and observers for the study period

year	*month*	*day*	*transects*	*observers*	*buddies*
2009	March	7th	7-18	Parrish-Kuhn, Frolli	Olson, Toews
2009	March	8th	1-6	Parrish-Kuhn	Frolli
2009	April	17th	7-18	Parrish-Kuhn, Frolli	Watson, Toews
2009	April	18th	1-6	Parrish-Kuhn	Frolli
2009	May	9th	7-18	Parrish-Kuhn, Frolli	Hallenbeck, Grounds
2009	May	10th	1-6	Parrish-Kuhn	Frolli
2009	June	8th	7-18	Parrish-Kuhn, Frolli	Lindholm, Grounds
2009	June	9th	1-6	Parrish-Kuhn	Frolli
2009	July	14th	7-18	Parrish-Kuhn, Frolli	Olson, Grounds
2009	July	15th	1-6	Parrish-Kuhn	Frolli
2009	August	3rd	1-18	Parrish-Kuhn, Olson	Frolli, Anderson
2009	September	9th	1-18	Parrish-Kuhn, Olson	Frolli, Vasquez
2009	November	3rd	1-18	Parrish-Kuhn, Olson	Frolli, Vasquez
2009	November	24th	1-18	Parrish-Kuhn, Olson	Frolli, Vasquez
2009	December	15th	1-18	Parrish-Kuhn, Olson	Frolli, Vasquez
2010	Feburary	12th	1-18	Parrish-Kuhn, Olson	Frolli, Toews
2010	March	22nd	1-18	Parrish-Kuhn, Olson	Watson, Toews
2010	April	16th	1-18	Parrish-Kuhn, Olson	Toews, Jefferies
2010	June	9th	1-18	Parrish-Kuhn, Olson	Halenbeck, Toews
2010	July	7th	1-18	Parrish-Kuhn, Olson	Halenbeck, Toews

APPENDIX D- ADDITIONAL INFORMATION ON STATISTICAL ANALYSIS.

Temporal variation in measured parameters

By sampling MacAbee reef approximately every four weeks for 18 months, we were able to characterize the any seasonal variation in the response variables with time. We considered four types of response variables: total abundance, species richness, family groups abundance, and individual species abundance because they have consistently been shown to be important indicators of population change (Stephens et al. 1984; Ebling & Laur 1986; Anderson 1994; Levin &Hay 1996; Jackson &Jones 1999; Magill & Sayer 2002). Total abundance was the total number of fish observed in one survey. Species richness was the total number of species observed in one survey. Family group abundance was number of fish observed in one survey within a phylogenetic family group. Individual species abundance was number of fish observed in one survey within an individual species. For all response variables an entire monthly survey was used as an individual sampling unit because although multiple transects are used in one survey, surveys were designed to include all transects as one sample, not as replicates.

For each of the four response variables, the overarching postulate examined in this study is: There is a non-zero relationship between the response variable and time (Appendix D). Based on this postulate, we made the following hypotheses:

$\mathbf{H_0}$ – There is no relationship between the response variable and time.
$\mathbf{H_1}$ – There is a linear relationship between the response variable and time.
$\mathbf{H_2}$ – There is a periodic relationship between the response variable and time.

We examined the relationship between the response variables and time using a generalized linear model (GLM) comparison with a negative binomial error distribution in the MASS package in the R statistical program (R Developmental Core Team 2008). The Negative Binomial error distribution was decided upon by assessing the standardized

residuals, leverage, and normal QQplots. (Neter et al 1985). In addition, count data showed significant over dispersion (variance is larger than the mean) indicating the Negative Binomial error distribution was most appropriate (Ismail & Jemain 2007).

The model comparison for each hypothesis was comprised of the following components:

$$H_0 : Y = \beta_0 \cdot tac + \varepsilon_i = 0$$

$$H_1 : Y = \beta_0 + \beta_1 t \cdot tac + \varepsilon_i$$

$$H_2 : Y = \beta_0 + \beta_1 \cos\left(\frac{2\pi}{P} t\right) + \beta_2 \sin\left(\frac{2\pi}{P} t\right) \cdot tac + \varepsilon_i$$

where:

Y was the response variable, β_0, $\beta_{1, \text{ and }} \beta_x$ were unknown coefficients, t was time in days, P was the known period, *tac* was the temporal autocovariance variable, and ε_i was the error term (Negative Binomial).

Table D.1 -Model hypotheses to be used in model comparison for each response variable.

	Null (H_0)	Trend (H_1)	Periodic (H_2)
Total Abundance (Y_1)	$H0 : Y1 = \beta0 \cdot tac + \varepsilon i = 0$	$H1 : Y1 = \beta0 + \beta1t \cdot tac + \varepsilon i$	$H2 : Y1 = \beta0 + \beta1\cos\left(\frac{2\pi}{P}t\right) + \beta2\sin\left(\frac{2\pi}{P}t\right) \cdot tac + \varepsilon i$
Species Abundance (Y_2)	$H0 : Y2 = \beta0 \cdot tac + \varepsilon i = 0$	$H1 : Y2 = \beta0 + \beta1t \cdot tac + \varepsilon i$	$H2 : Y2 = \beta0 + \beta1\cos\left(\frac{2\pi}{P}t\right) + \beta2\sin\left(\frac{2\pi}{P}t\right) \cdot tac + \varepsilon i$
Species Richness (Y_3)	$H0 : Y3 = \beta0 \cdot tac + \varepsilon i = 0$	$H1 : Y3 = \beta0 + \beta1t \cdot tac + \varepsilon i$	$H2 : Y3 = \beta0 + \beta1\cos\left(\frac{2\pi}{P}t\right) + \beta2\sin\left(\frac{2\pi}{P}t\right) \cdot tac + \varepsilon i$
Family Group Abundance (Y_4)	$H0 : Y4 = \beta0 \cdot tac + \varepsilon i = 0$	$H1 : Y4 = \beta0 + \beta1t \cdot tac + \varepsilon i$	$H2 : Y4 = \beta0 + \beta1\cos\left(\frac{2\pi}{P}t\right) + \beta2\sin\left(\frac{2\pi}{P}t\right) \cdot tac + \varepsilon i$

For each response variable we compared the models using the Akaike's Information Criteria (AIC) approach to examine the influence of the predictor on the response variable (Burnham and Anderson 1998, 2002, 2004). We calculated the AIC weight (AIC_w), which represents the probability that each model was the best-fit model, AIC_C for small sample sizes, and ΔAIC for each model and presented these results in an

AIC comparison table. For each comparison, from the model with the lowest AIC_C values, we inferred which model was best able to predict the response variable (Y) (Burnhan & Anderson 2004). In addition, an evidence ratio (ER) was calculated to quantify the strength of the evidence supporting the best-fit model (Burnham and Anderson 2002, 2004).

For species abundance and family group abundance the AIC was run separately for each species or group of species and only species or groups that were present in 80% of the surveys were used (Micheli & Halpern 2005). Temporal autocorrelation was investigated using the autocorrelation function (ACF) in R. Those response variables that had an AR>0, were run using a Generalized Least Squared model (GLS) in the nlme package in R, which allows for an autocorrelation term in the model (Bolker 2008). For each of the response variables, if the H_2 hypothesis was supported, we calculated the phase and amplitude.

Sampling Frequency

The detection of long-term trends can be difficult because trends may be obscured by short-term variation (Maxwell and Jennings 2005). For instance, if we measure abundance at the start of a three-year period and again at the end and find it is equal, this may indicate a true downward trend or may be the result of a favorable first year and unfavorable last year (Lesica and Steele 1996). This same concept can be applied to monitoring done once a year; differences seen between years may be influenced by smaller-scale variation within the year. As the variation between sampling periods increases, longer time scales are needed to accurately identify trends, which can delay management actions (Dayton et al 1992, Costanza et al 1999). Sampling must therefore be sufficient to identify patterns of change at a scale equivalent to the natural variation in the population (Underwood 1994). It is important to identify what scale sampling would need to be done to include seasonal patterns in the larger-scale time series (Figure D1).

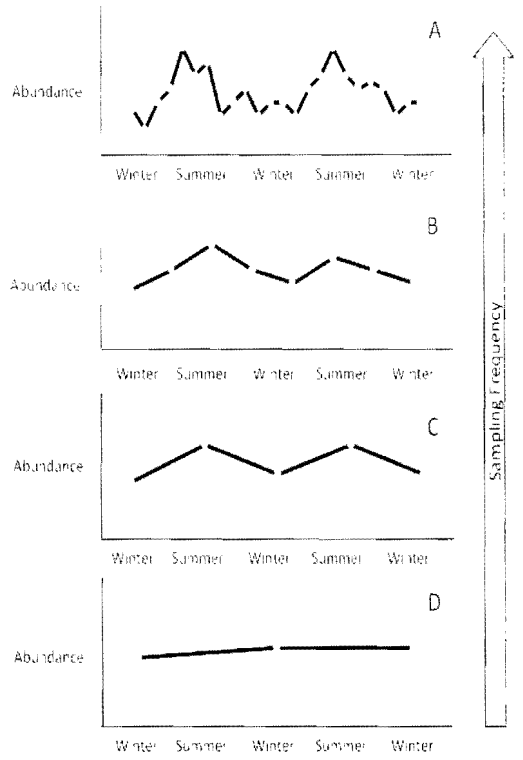


Figure D.1- Hypothetical monthly abundance values. As sampling rate increases, seasonal patterns become more clear.

I evaluated the implications of temporal variations in fish communities for monitoring data collected less frequently by sub-sampling the 18 months of data at multiple frequencies. For each response variable for which the $\mathbf{H_2}$ hypothesis was accepted, I subsampled at 6 sample per year intervals and re-ran the model comparison. By doing this analysis I was able to identify if a less frequent sampling interval will show a relationship with time, and thus able to identify which sampling interval was necessary to detect seasonal variations.

Temporal Autocorrelation

Temporal autocorrelation must be addressed with samples taken along a time series because the observations at each time period may be similar to those in the next time period because they are temporally close to each other (Bolker 2008). We

investigated for temporal autocorrelation using the auto correlation function (acf) in R, which creates a plot of the autocorrelation of the variable: the correlation of observations with other observations a given lag distance away (Bolker 2008). To test for the order of autocorrelation we used model selection, which performs auto regressions on the variable at all possible lags and determines what order is the most parsimonious using AIC. Embiotocidae group was the only response variable to test positive for temporal autocorrelation with an AR (1), and therefore the AIC analysis was run using a Generalized Least Squared model (GLS) in the nlme package in R was used, which allows for an autocorrelation term in the model. Embiotocidae group was the only response variable to test positive for temporal autocorrelation with an AR (1), and therefore the AIC analysis was run using the GLS method.

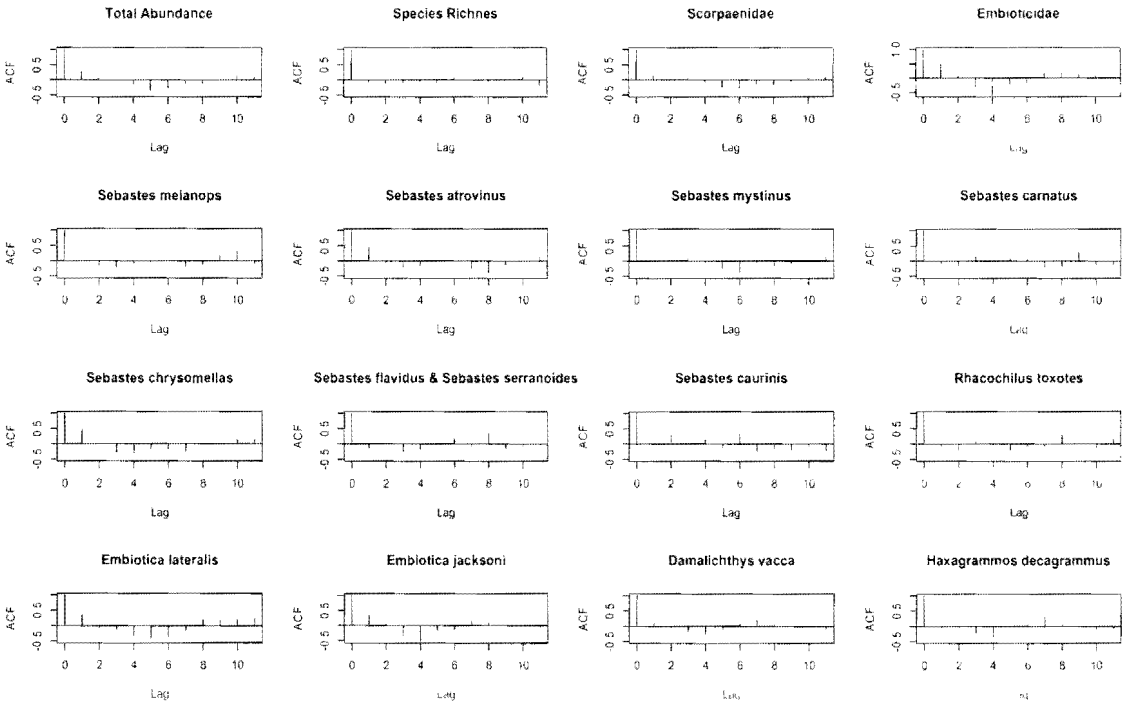


Figure D.2 Autocorrelation plots for each response variable.

APPENDIX E – VISIBILITY ANALYSIS

It is generally accepted that water clarity or visibility can affect both the abundance and type of species seen by observers (Sale &Douglas 1981). Although Reef Check California requires a minimum visibility of 5m to conduct a survey, it is valid to question weather visibility greater than 5m would result in increased observations. To investigate the affect of visibility on the total abundance, species abundance, and richness of fish observed in this study we ran one-way Analysis of Variance (ANOVA) for each response variable used in part 1. Visibility was estimated in the field at the beginning of each dive and post hoc surveys were grouped into high (8-9.5m) medium (6.5-8m), and low (5-6.5m) visibility categories. To assess whether the residuals from the one-way ANOVA models were normally distributed qualitative approaches were taken, including the inspection of the standardized residuals, Leverage, and examination of normal QQplots (Neter et al 1985); as well as the application of the Shapiro-Wilks test (Shapiro & Wilks 1965). All response variables had normal distributions except for *S. mystinus*, Pile Embiotocidae, and Rockfish Group which were square-root transformed to satisfy normality requirements. Homogeneity of variance assumptions were confirmed for each taxon using Bartlett's test statistic. Results of ANOVA tests showed that there is no significant difference between visibility classifications for any of the response variables used in this analysis (Table E.1)

Table E.1 ANOVA tests of the visibility categories for each response variable

	DF	*Sum Sq*	*Mean Sq*	*F ratio*	*Probability*
Total Abundance					
Visibility	2	14.64	7.32	1.05	0.38
Residuals	12	83.30	6.94		
Scorpaenidae					
Visibility	2	20.29	10.15	1.38	0.29
Residuals	12	88.00	7.33		
Embiotocidae					
Visibility	2	42.16	21.08	0.15	0.86
Residuals	12	1677.57	139.80		
Sebastes atrovinus					
Visibility	2	194.80	97.40	2.76	0.10
Residuals	12	422.80	35.23		
Sebastes carnatus					
Visibility	2	19.56	9.78	3.89	0.05
Residuals	12	30.18	2.51		
Sebastes flavidus/ Sebastes serranoides					
Visibility	2	0.56	0.28	0.41	0.67
Residuals	12	8.22	0.68		
Sebastes melanops					
Visibility	2	3.95	1.98	3.16	0.08
Residuals	12	7.51	0.63		
Sebastes mystinus					
Visibility	2	18.66	9.33	0.95	0.41
Residuals	12	118.13	9.84		
Damalichthys vacca					
Visibility	2	0.19	0.10	0.18	0.84
Residuals	12	6.55	0.55		
Embiotica lateralis					
Visibility	2	34.23	17.11	0.60	0.56
Residuals	12	340.18	28.35		
Embiotica jacksoni					
Visibility	2	2.95	2.98	4.16	0.09
Residuals	12	8.21	0.83		
Rhacochillus vacca					
Visibility	2	1.61	0.81	0.51	0.61
Residuals	12	15.75	1.58		
Hexagrammus decagrammus					
Visibility	2	24.09	12.05	1.36	0.30
Residuals	12	88.68	8.87		

Appendix F- Supporting Result Tables

Table F.1 AIC tables for each response variable with monthly sampling

	df	*AIC*	*AICc*	*delAIC*	*AICw*
Total Abundance					
Null (H_0)	2	159.81	160.81	2.58	0.20
Linear (H_1)	3	160.78	162.97	4.74	0.06
Periodic (H_2)	4	154.23	158.23	0.00	0.73
Richness					
Null (H_0)	2	75.28	76.28	0.00	0.78
Linear (H_1)	3	77.19	79.37	3.09	0.17
Periodic (H_2)	4	77.85	81.85	5.57	0.05
Scorpaenidae					
Null (H_0)	2	152.72	153.73	1.58	0.28
Linear (H_1)	3	153.37	155.55	3.40	0.11
Periodic (H_2)	4	148.15	152.15	0.00	0.61
Embiotocidae					
Null (H_0)	2	115.59	116.59	1.18	0.33
Linear (H_1)	3	117.36	119.54	4.13	0.07
Periodic (H_2)	4	111.41	115.41	0.00	0.59
Sebastes atrovirens					
Null (H_0)	2	100.67	101.67	0.00	0.53
Linear (H_1)	3	100.44	102.62	0.95	0.33
Periodic (H_2)	4	100.36	104.36	2.69	0.14
Sebastes carnatus					
Null (H_0)	2	55.90	56.82	3.69	0.14
Linear (H_1)	3	51.13	53.13	0.00	0.86
Periodic (H_2)	4	58.84	62.48	9.35	0.01
Sebastes caurinus					
Null (H_0)	2	54.75	55.76	0.99	0.47
Linear (H_1)	3	52.58	54.76	0.00	0.61
Periodic (H_2)	4	57.89	61.89	7.14	0.02
Sebastes chrysomelas					
Null (H_0)	2	35.60	36.52	0.00	0.70
Linear (H_1)	3	37.40	39.39	288.00	0.17
Periodic (H_2)	4	36.19	39.82	3.30	0.13
Sebastes flavidus/ Sebastes serranoides					
Null (H_0)	2	50.55	51.47	0.00	0.68
Linear (H_1)	3	51.29	53.29	1.82	0.28
Periodic (H_2)	4	53.51	57.15	5.68	0.04
Sebastes melanops					
Null (H_0)	2	55.90	56.83	0.00	0.64
Linear (H_1)	3	56.90	58.91	2.08	0.23
Periodic (H_2)	4	56.26	59.99	2.07	0.14

	df	*AIC*	*AICc*	*delAIC*	*AICw*
Sebastes mystinus					
Null (H_0)	2	141.42	142.42	1.80	0.26
Linear (H_1)	3	142.47	144.65	4.04	0.08
Periodic (H_2)	4	136.61	140.61	0.00	0.65
Damalichthys vacca					
Null (H_0)	2	77.04	78.04	27270.00	0.34
Linear (H_1)	3	75.59	75.59	0.00	0.39
Periodic (H_2)	4	74.47	78.47	0.70	0.27
Embiotica lateralis					
Null (H_0)	2	95.52	96.52	10.39	0.01
Linear (H_1)	3	97.44	99.62	13.48	0.00
Periodic (H_2)	4	82.14	86.13	0.00	0.99
Embiotica jacksoni					
Null (H_0)	2	93.52	94.53	0.00	0.67
Linear (H_1)	3	95.46	97.64	3.11	0.14
Periodic (H_2)	4	93.06	97.06	2.53	0.19
Rhachochillus toxotes					
Null (H_0)	2	36.78	38.12	0.00	0.67
Linear (H_1)	3	37.45	42.33	288.00	0.17
Periodic (H_2)	4	36.00	41.92	3.30	0.15
Hexagrammos decagrammus					
Null (H_0)	2	80.12	81.12	0.00	0.72
Linear (H_1)	3	81.20	83.38	2.26	0.23
Periodic (H_2)	4	82.65	86.65	5.53	0.04

Table F.2 AIC Tables for each response variable not including small *S. mystinus* with monthly sampling

	df	*AIC*	*AICc*	*delAIC*	*AICw*
Total Abundance					
Null (H_0)	2	146.23	147.23	0	0.59
Linear (H_1)	3	146.98	149.17	1.93	0.22
Periodic (H_2)	4	145.48	149.48	2.25	0.19
Sebastes mystinus					
Null (H_0)	2	111.1	112.1	0	0.63
Linear (H_1)	3	111.24	113.43	1.33	0.33
Periodic (H_2)	4	113.66	117.66	5.56	0.04
Scorpaenidae					
Null (H_0)	2	133.3	134.3	0	0.54
Linear (H_1)	3	132.78	134.97	0.67	0.39
Periodic (H_2)	4	134.45	138.45	4.15	0.07
Small Sebastes mystinus					
Null (H_0)	2	126.46	127.46	4.73	0.08
Linear (H_1)	3	128.12	130.3	7.58	0.02
Periodic (H_2)	4	118.73	122.73	0	0.89

Table F.3 AIC Tables for each response variable with bi-monthly sampling

	df	*AIC*	*AICc*	*delAIC*	*AICw*
Total Abundance					
Null (H_0)	2	73.16	75.56	0.93	0.38
Linear (H_1)	3	68.62	74.62	0	0.61
Periodic (H_2)	4	76.26	89.6	14.97	0.01
Perch					
Null (H_0)	2	64	66.4	0	0.93
Linear (H_1)	3	65.62	71.62	5.22	0.07
Periodic (H_2)	4	65.99	79.32	12.92	0
Sebastes mystinus					
Null (H_0)	2	52.43	54.82	0	0.88
Linear (H_1)	3	52.88	58.88	4.06	0.12
Periodic (H_2)	4	55.07	68.4	13.58	0
Embiotica lateralis					
Null (H_0)	2	50.12	52.52	0	0.87
Linear (H_1)	3	51.94	57.94	5.41	0.06
Periodic (H_2)	4	44.12	57.46	4.93	0.07

Table F.4 Results of Students t-test between hydrographic seasons

	t	*df*	*Probability*
Total Abundance	-2.03	10.39	0.07
Richness	-1.16	12.69	0.27
Scorpaenidae	-2.27	12.51	0.04
Embiotocidae	-1.49	12.74	0.16
Sebastes atrovirens	-1.81	9.03	0.11
Sebastes carnatus	-1.14	12.82	0.28
Sebastes caurinus	-0.49	12.17	0.63
Sebastes chrysomelas	-2.35	12.96	0.04
Sebastes flavidus/ Sebastes serranoides	0.03	12.49	0.98
Sebastes melanops	-1.72	9.31	0.12
Sebastes mystinus	-2.14	12.73	0.05
Damalichthys vacca	1.18	8.81	0.27
Embiotica lateralis	-5.06	10.72	0.00
Embiotica jacksoni	-0.16	13.01	0.88
Rhachochillus toxotes	-2.27	9.87	0.05*
Hexagrammos decagrammus	0.36	7.98	0.73

Table F.5 Results of Students t-test between hydrographic seasons excluding all small *S. mystimus*

	t	df	Probability
Total Abundance	-2.15	12.70	0.05
Scorpaenidae	-2.30	10.37	0.04
Sebastes mystinus	-2.14	12.73	0.08
Small Sebastes mystinus	-3.01	11.25	0.01

APPENDIX G - COMPARISON TO LONG-TERM DATA

Our results are discussed here in the context of long-term data collected by PISCO, where any apparent similarities and/or differences in the data may inform the broader goal of understanding the implications of sampling frequency. Although we do not provide an explicit quantitative comparison of our data to PISCO data, the fact that longer-term data exists for the same area warrants a simple comparison.

In order to standardize the two datasets we identified shared species, and grouped species in the PISCO dataset that were originally grouped in the RCCA dataset (i.e. canary/vermillion rockfish). To account for the fact that PISCO identifies young of the year rockfish and RCCA does not, we did not include any fish below 16cm from the PISCO dataset and also did not include any "small" classcode from the RCCA dataset. This decision was made because it was impossible to tell which small rockfish were the YOY morphology at time of identification in the PISCO dataset. There are

There are several differences between the PISCO and RCCA sampling designs, which also required modifications to both datasets so the two, could be compared. Every PISCO site includes a full up coast and down coast survey; in this analysis we only used the down coast MacAbee survey which is the same geographical location as the RCCA MacAbee survey. PISCO conducts bottom, midwater, and canopy surveys for every transect; however, in this analysis only PISCO's bottom survey was used. Although the individual strip transect methods are identical between the two organizations, PISCO conducts 12 transects, and RCCA conducts 18 in a survey; therefore both datasets were transformed to observations per transect.

Our results showed that the total abundance and family abundance counts during the upwelling season all fall within the range of abundances observed over the past ten annual surveys conducted by PISCO, suggesting that stochastic intra-seasonal variations can significantly influence estimates of species abundances. If PISCO or RCCA did not pay close attention to sampling at the same time annually, changes to the populations would have to exist on a scale greater than the within season variation in order to be

detected. PISCO and RCCA may be detecting true changes in the fish populations on an annual basis; however, they are unable to reject the possibility that their data are influenced by natural stochastic variation. PISCO attempts to ameliorate the issue of seasonal variation by sampling at the same time each year, in late summer when species counts are highest, and by conducting two replicate surveys per site or four replicate surveys per MPA. Magill and Sayer (2002) suggested that summer estimates are more likely to be an accurate reflection of actual abundance because it is during the upwelling season when more fish are at shallower depths, and because of the lack of storms fish are more likely not to be hiding in refuge. However, the opportunity to increase sampling effort within the upwelling season would reduce error around the annual estimates and increase power to detect inter-annual trends.

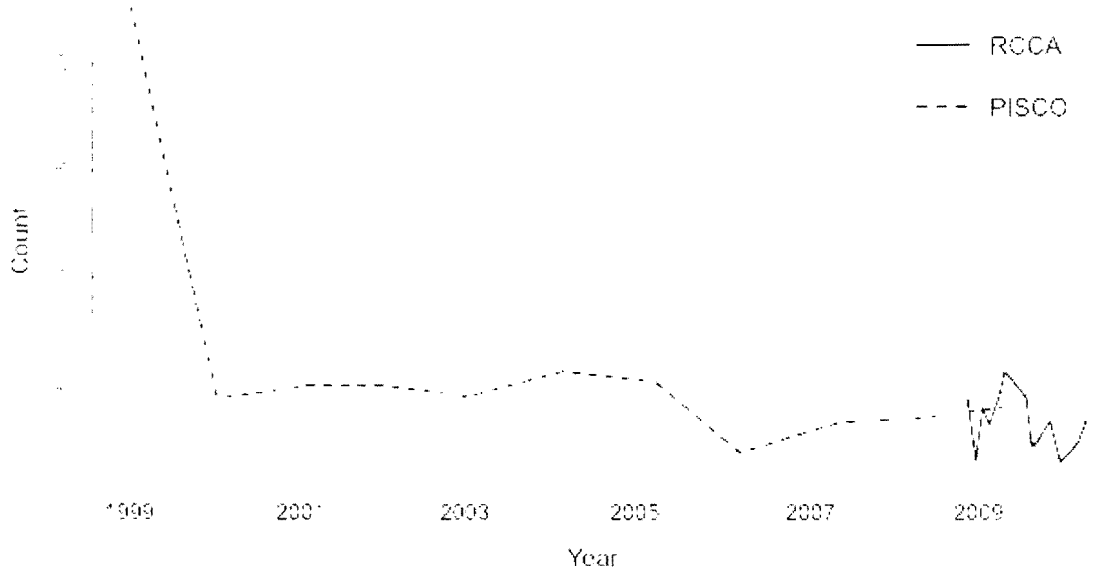


Figure G.1- Total abundance counts for all species shared on both RCCA and PISCO species lists per transect from PISCO annual surveys from 1999-2009 and RCCA monthly surveys from March 2009 to July 2010.

R CODE OF STATISTICAL ANALYSIS

The following R code was used to define models and run model comparisons, as well as perform t-tests. The term "Response" always corresponds to the particular response variable that is tested. "Week" refers to the independent variable. Commands used to read, format, or plot the data are excluded. The symbol # indicates a comment and is not a command.

##AIC Analyses

```
library(MASS); library(nlme) ## These two packages contain functions that are used in the following code.

## Defining Models

Response.fit0<-glm.nb(Response~1, data=fish, link="identity") ## Null Model

Response.fit1 <- glm.nb(Response~Week, data=fish,link="identity") ## Linear

radians = 2 * pi * Week / 52
Response.fit3 <- glm.nb(Response~ sin(radians) + cos(radians),data=fish,link=
"identity") ## Periodic

##Defining AIC Table

fredsAICtable <- function( aic, n) {K <- aic$dfAICc <- aic$AIC + 2 * K * (K+1) / ( n - K - 1 )delAIC<- AICc - min( AICc )AICw <- exp( 0.5*delAIC) / sum( exp(-0.5*delAIC))
```

```
data.frame( aic, AICc, delAIC , AICw)}

## Publishing AIC Table

fredsAICtable( AIC ( Response.fit0, Response.fit1,Response.fit4) , length(Response) )

## Calculating Evidence Ratio

aic<-fredsAICtable( AIC ( Response.fit0, Response.fit1,Response.fit4) ,
length(Response) )

EvidenceRatio_fit4_fit2 = aic[3,5] / aic[1,5]
```

##AIC with Temporal Autocorrelation

```
Response.ts = ts(Response, frequency=12)  #Create a time series

Acf.Response<-acf(Response.ts[,3],ci.type="ma",na.action=na.exclude) # Tests for
correlation

## Defining Models

Response.ts.gls0<-gls(Response.ts~1,data=Response.ts, na.action=na.exclude,
correlation=corARMA(value=c(correlation value), p=1)) # Null Model

perch.ts.gls1<-gls(fish.ts[,7]~fish.ts[,1],data=fish.ts, na.action=na.exclude,
correlation=corARMA(value=c(correlation value), p=Correlation value)) # Linear Model
```

```
Response.ts.gls4 <-  gls(Response.ts[,7] ~ sin(2 * pi * Response.ts[,1] / 52) + cos(2 * pi *
Response.ts[,1] / 52), data=Response.ts, na.action=na.exclude,
correlation=corARMA(value=c(correlation value), p=1)) # Periodic Model

## Define AIC Table

fredsAICtable <- function( aic, n) {K <- aic$dfAICc <- aic$AIC + 2 * K * (K+1) / ( n - K
- 1 )delAIC<- AICc - min( AICc )AICw <- exp(-0.5*delAIC) / sum( exp(-0.5*delAIC))
data.frame( aic, AICc, delAIC , AICw)}

##Publishing AIC Table

fredsAICtable( AIC ( Response.fit0, Response.fit1,Response.fit4) , length(Response) )

##Calculating Evidence Ratio

aic<-fredsAICtable( AIC ( Response.fit0, Response.fit1,Response.fit4) ,
length(Response) )
```

##T-test

```
shapiro.test(Response) # Test for Normality

qqnorm(Response);qqline(Response, col = 2) # Investigate for Normality

t.test(Response~Season)
```